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CALIBRATION OF THE GAIA RVS FROM GROUND-BASED OBSERVATIONS OF CANDIDATE STANDARD STARS

L. Chemin¹, C. Soubiran¹, F. Crifo², G. Jasiewicz³, D. Katz², D. Hestroffer⁴ and S. Udry⁵

Abstract. The Radial Velocity Spectrometer (RVS) on board of Gaia will perform a large spectroscopic survey to determine the radial velocities of some 1.5×10^8 stars. We present the status of ground-based observations of a sample of 1420 candidate standard stars designed to calibrate the RVS. Each candidate star has to be observed several times before Gaia launch (and at least once during the mission) to ensure that its radial velocity remains stable during the whole mission. Observations are performed with the high-resolution spectrographs SOPHIE, NARVAL and CORALIE, completed with archival data of the ELODIE and HARPS instruments. The analysis shows that about 7% of the current catalogue exhibits variations larger than the adopted threshold of 300 m s^{-1} . Consequently, those stars should be rejected as reference targets, due to the expected accuracy of the Gaia RVS. Emphasis is also put here on our observations of bright asteroids to calibrate the ground-based velocities by a direct comparison with celestial mechanics. It is shown that the radial velocity zero points of SOPHIE, NARVAL and CORALIE are consistent with each other, within the uncertainties. Despite some scatter, their temporal variations remain small with respect to our adopted stability criterion.

Keywords: Galaxy: kinematics and dynamics, Galaxy: structure, Stars: kinematics and dynamics, Minor planets, asteroids: general, Surveys, Techniques: radial velocities

1 Generalities

The RVS is a slitless spectrograph whose spectral domain is 847-874 nm and resolving power $R \sim 11500$. The expected accuracy is 1 km s^{-1} for F0 to K0 stars brighter than $V=13$, and for K1 to K4 stars brighter than $V=14$.

The main scientific objectives of RVS are the chemistry and dynamics of the Milky Way, the detection and characterisation of multiple systems and variable stars (for more details, see Wilkinson et al. 2005). Those objectives will be achieved from a spectroscopic survey of:

- Radial velocities ($\sim 150 \times 10^6$ objects, $V \leq 17$)
- Rotational velocities ($\sim 5 \times 10^6$ objects, $V \leq 13$)
- Atmospheric parameters ($\sim 5 \times 10^6$ objects, $V \leq 13$)
- Abundances ($\sim 2 \times 10^6$ objects, $V \leq 12$)

Each star will be observed ~ 40 times on average by RVS over the 5 years of the mission.

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2 Calibration of the Gaia RVS

Because the RVS has no calibration module on board, the zero point of its radial velocities has to be determined from reference sources. Ground-based observations of a large sample of well-known, stable reference stars as well as of asteroids are thus critical for the calibration of the RVS. A sample of 1420 candidate standard stars has been established (Crifo et al. 2009, 2010) and has to be validated by high spectral resolution observations.

Two measurements per candidate star are being made before Gaia is launched (or one, depending on already available archived data). Another measurement will occur during the mission. The measurements will allow us to check the temporal stability of radial velocities, and to reject any targets with significant RV variation.

3 Status of observations of stars

The ongoing observations are performed with three high spectral resolution spectrographs:

- SOPHIE on the 1.93-m telescope at Observatoire de Haute-Provence,
- NARVAL on the T  lescope Bernard Lyot at Observatoire Pic-du-Midi,
- CORALIE on the Euler swiss telescope at La Silla.

As of June 2011 we have observed 995 distinct candidates with SOPHIE, CORALIE and NARVAL. The detailed observations per instrument are:

- 691 stars (1165 velocities) with SOPHIE
- 669 stars (945 velocities) with CORALIE
- 93 stars (98 velocities) with NARVAL

Figure 1 (left-hand panel) represents the spatial distribution in the equatorial frame of the sample and the number of measurements per object we have done so far with the three instruments.

In addition to those new observations, we use radial velocity measurements available from the spectroscopic archives of two other high-resolution instruments: ELODIE, which is a former OHP spectrograph, and HARPS which is currently observing at the ESO La Silla 3.6-m telescope. The archived data allow us to recover 1057 radial velocities for 292 stars (ELODIE) and 1289 velocities for 113 stars (HARPS).

Figure 1 (right-hand panel) summarizes the status of the total number of measurements for the sample of 1420 candidate stars performed with all five instruments.

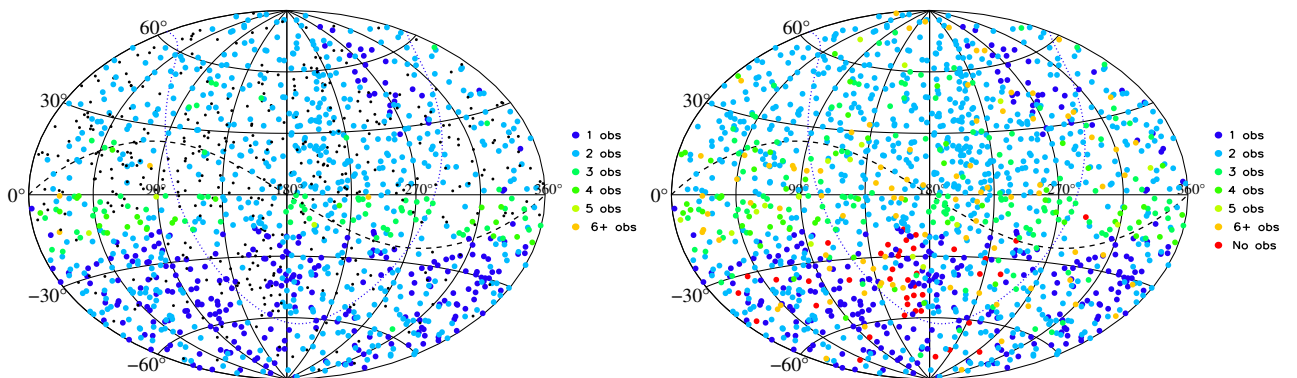


Fig. 1. Left panel: Current status of the number of observations available per candidate standard star observed with the SOPHIE, CORALIE and NARVAL instruments (995 distinct stars). Black dots indicate the locations of the 425 remaining sources from the sample of 1420 candidates. **Right panel:** Same as in left panel, but including archival data of the ELODIE and HARPS instruments as well. The maps are represented in the equatorial frame. The Ecliptic plane is shown as a dashed line and the Galactic plane as a dotted line.

4 How stable are the radial velocities of our candidates?

We have derived the variation of radial velocity of each star for which we have at least two velocity measurements separated by an elapsed time of at least 100 days. These stars represent a subsample of 1044 among 1420 targets. The variation is defined as the difference between the maximum and minimum velocities, as reported in the frame of the SOPHIE spectrograph. Its distribution is displayed in Figure 2.

A candidate is considered as a reference star for the RVS calibration when its radial velocity does not vary by more than an adopted threshold of 300 m s^{-1} . Such a threshold has been defined to satisfy the condition that the variation of the RV of a candidate must be well smaller than the expected RVS accuracy (1 km s^{-1} at best for the brightest stars). As a result, we find $\sim 7\%$ of the 1044 stars exhibiting a variation larger than 300 m s^{-1} , as derived from available measurements performed to date. Those variable stars will have to be rejected from the list of standard stars. Note that about 75% of the 1044 stars have very stable RV, at a level of variation smaller than 100 m s^{-1} .

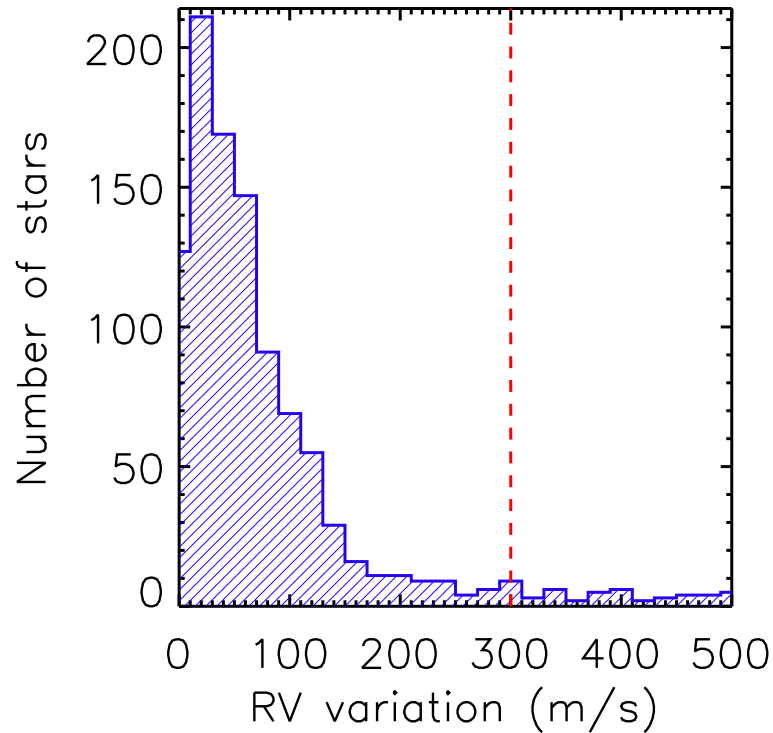


Fig. 2. Distribution of variations of radial velocities of candidate standard stars having at least two RV measurements separated by 100 days or more. A dashed line shows the adopted 300 m s^{-1} stability threshold.

5 Spectral observations of asteroids

Observations of asteroids are very important for the radial velocity calibration. Indeed they will be used to determine the zero-points of the RVs measured with SOPHIE, CORALIE and NARVAL (as well as the Gaia-RVS zero-point). Those goals will be achieved by comparing the spectroscopic RVs of asteroids from ground-based measurements with theoretical kinematical RVs from celestial mechanics. The theoretical RVs are provided by IMCCE and are known with an accuracy better than 1 m s^{-1} . About 280 measurements of 90 asteroids have been done so far.

As an illustration, Figure 3 (left-hand panel) displays the residual velocity (observed minus computed RVs) of asteroids observed by the SOPHIE instrument as a function of the observed RVs. The average residual of asteroids observed with SOPHIE is 30 m s^{-1} and the scatter is 38 m s^{-1} .

In Figure 3 (right-hand panel) we also show the variation of the residual RVs with time. It nicely shows how

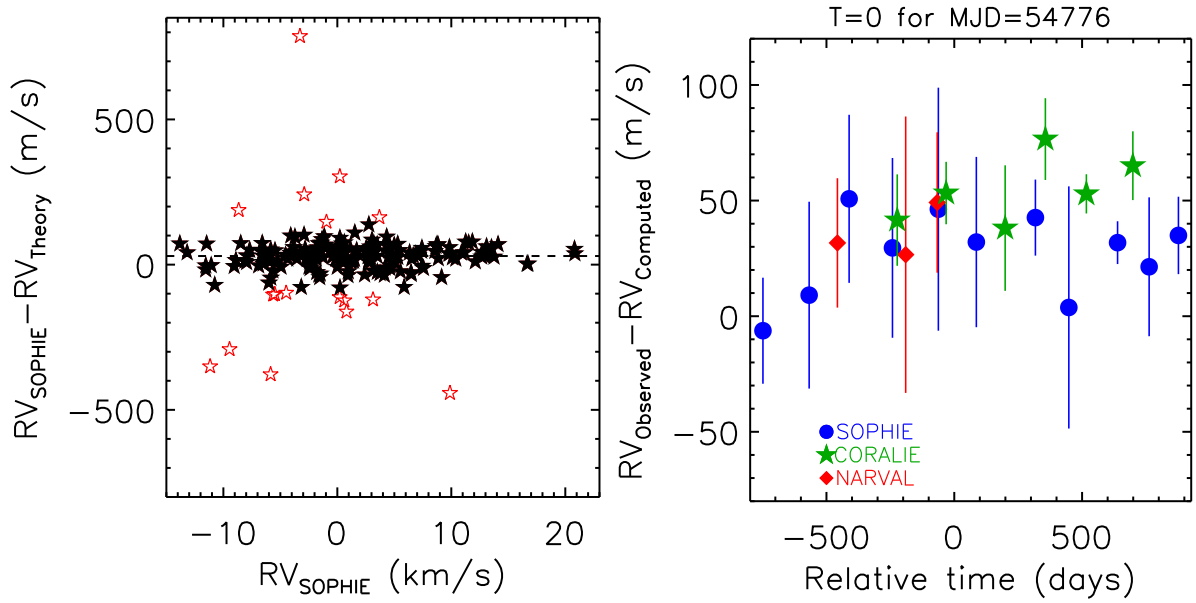


Fig. 3. Radial velocities of asteroids. **Left panel:** Residual velocities (observed minus computed) of asteroids as a function of their observed velocities (SOPHIE observations only). Red symbols are points deviant by more than 3σ . A horizontal dashed line represents the mean residual velocity of 30 m s^{-1} . **Right panel:** Comparison of residual velocities of asteroids for SOPHIE, CORALIE and NARVAL as a function of time for the various observing runs.

stable the RVs are as a function of time. The residual RVs are relatively constant within the quoted errors. The error-bars represent the dispersion of all measurements performed at each observational run. Their amplitude is mainly related to the conditions of observations that differ from one session to another (in particular the moonlight contamination). Though significant (between 10 and 50 m s^{-1}) those error-bars remain smaller than our target stability criterion of 300 m s^{-1} , which will enable us to determine correctly the RV zero point of each instrument.

Note also we have verified that intrinsic properties of asteroids (e.g. their size, shape, rotation velocity, albedo, etc...) have negligible systematic impacts on the determination of RVs zero points for the spectrographs. From now, observations of asteroids shall be performed with reduced moonlight contamination

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